Using mass-flow controllers for obtaining extremely stable ECR ion source beams

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Abstract

Beam stability and reproducibility is of paramount importance in applications requiring precise control of implanted radiation dose, like in the case of hadrontherapy. The beam intensity over several weeks or months should be kept constant. Moreover, the timing for changing the nature of the beam and, as a consequence, the tuning of the source should be minimized. Standard valves usually used in conjunction of ECR ion sources have the disadvantage of controlling the conductance, which can vary significantly with external conditions, like ambient temperature and inlet pressure of the gas. The use of flow controllers is the natural way for avoiding these external constraints. In this contribution we present the results obtained using a new model of Mass-flow controller in the Supernanogan [1] source, for production of C^{4+} and H^{3+} beams. Extremely stable beams (+/- 2.5%) without retuning of the source over several weeks can be obtained. The reproducibility of the source tuning parameters can also be demonstrated.

GAZ SYSTEM

The previous Pantechnik's gas system using UDV 140 thermo-valve has been replaced by Mass flow-controller but keeping in state the rest of the system (see Fig. 1).

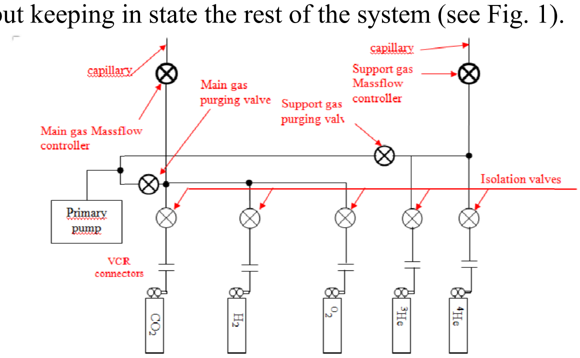

Figure 1: Schematic Gas System

The sensor's principle [2] inside the Mass flow-controller is made of a stainless steel capillary tube with resistance thermometer elements (see Fig. 2). A part of the gas flows through this bypass sensor, and is warmed up by heating elements. Consequently the measured temperatures T1 and T2 drift apart. The temperature difference is directly proportional to mass flow through the sensor. In the main channel Bronkhorst Company applies a patented laminar flow element consisting of a stack of stainless steel discs with precision-etched flow channels. Thanks to the flow-split the sensor output is proportional to the total mass flow rate. The minimum flow with this system is 0.014 mln/min until 0.06ml$_n$/min at max aperture.

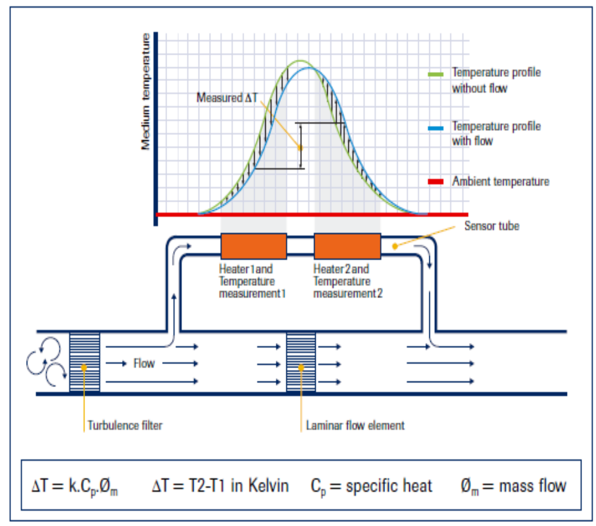

Figure 2: Mass-Flow sensor's principle

SYSTEM REACTIVITY AND STABILITY WITH TEMPERATURE

The behaviour of the Mass flow controller has been studied for different temperature variations.

Reactivity with sudden temperature changes

We recorded the current beam during 6400s and forced the temperature of the test room from 22°C to 14°C in 25 minutes (Fig. 3 & Table 1). The Mass-flow is only sensitive to very high variation of temperature.

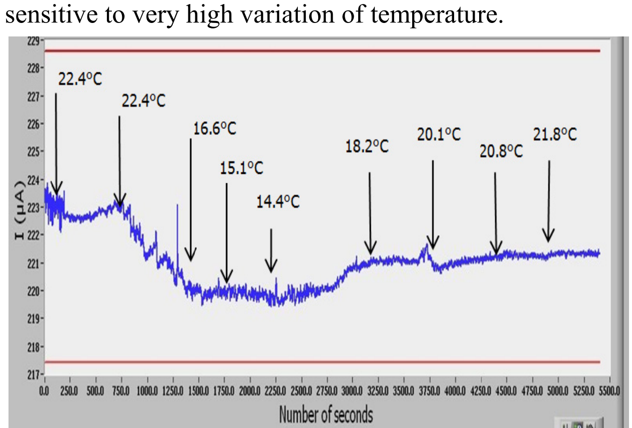

Figure 3: C^{4+} current with huge temperature's room variations.

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Nevertheless, it stays under stability requirements limit (223µA +/- 2.5%).

Table 1: Test-room's temperatures

Time (s)	Temperature °C	I(µA)
0	22.4°C (start stability file)	223
600	22.4°C (start air cooler, set to 16°C)	223.5
1200	16.6°C	220
1800	15.1°C	220
2400	14.4°C (stop air cooler)	220
3000	16.6°C	221
3600	18.2°C	221
4200	20.1°C	221
4800	20.8°C	222
5400	21.2°C	222

Beam evolution during long term period

The Fig. 4 graphic shows the evolution of the beam during 1 hour using UDV valves and Mass Flow Controller.

The big wave observed is due to the start and stop of the air-conditioning system in Pantechnik's test-room.
The Mass-flow is insensitive to low variation of temperature (+-2°C) which is a requirement for Hadrontherapy [3].

The mean noise is lower with Mass Flow, the reason is the following: The gas mixing rate between support and main gas is maintained constant with the two Mass Flow while it can change with UDV140.

The Fig. 5 shows the evolution of the beam during 10 hours using UDV valves. The test with Mass-flow is in progress at Marburg's Hadrontherapy Center.

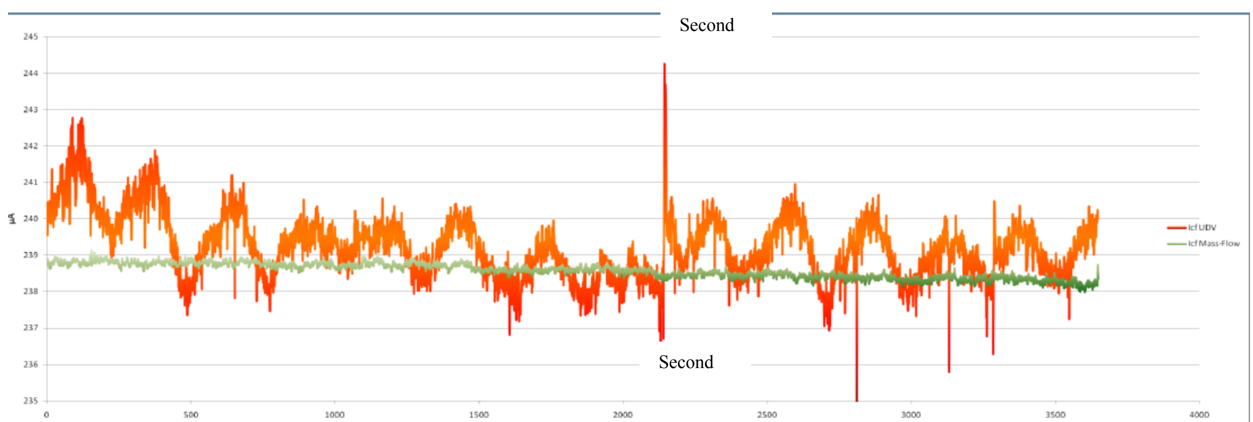

Figure 4: C^{4+} stability during 1 hour.

Figure 5: C^{4+} stability during 10 hours.

SYSTEM REPRODUCIBILITY WHEN CHANGING THE FLOW

In order to demonstrate the reproducibility of the system, the flow of the He gas has been changed and came back to the original value (see Fig. 6). There is no hysteresis effect like in UDV dosing valve and the reactivity is <5s.

The flow can be adjusted to the set point with a ramp (arrows 2, 4, 5, 6) or without (arrows 1, 3).

The flow has been changed with a step= 0.5% (of the max aperture) on arrow 1 and 2.

The ion source is insensitive to changes smaller than 0.5% for this tuning.

On arrows 3, 4 and 5, 6, the flow has been changed with a step=+/-1.25% , the ion beam current is restored.

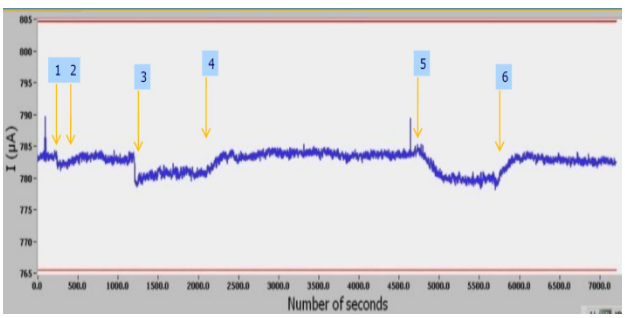

Figure 6: System reproducibility with He^+.

INJECTION PRESSURE ACCURACY

Fig. 7 & 8 display the result of test made on Supernanogan with injection turbo-pump. A calibration curve has been done on 2 different gases in order to investigate the behaviour of the valve and its resolution. We recorded (by step of 0.1% of the maximum flow) the injection pressure (without beam).

The opening is linear and the step resolution is around 1.4E-7 mbars.

The response time is less than 3s for small step.

The range goes to 2.10^{-7} to 5.10^{-5} mbar with He Gas and 2.10^{-7} to 2.10^{-4} mbar with H_2.

We conclude that we can have a very good accuracy on the flow. Nevertheless, further tests with others gases and high charge state will be studied in a close future.

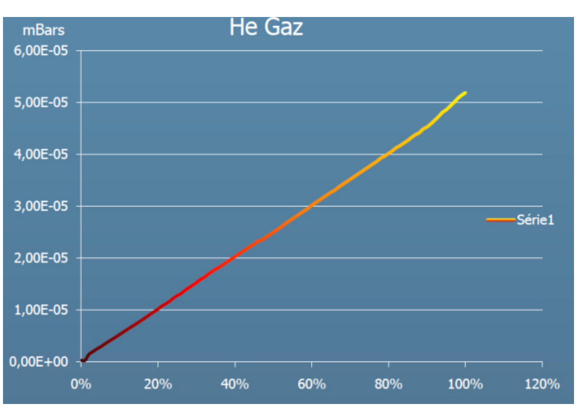

Figure 7: System reproducibility with He.

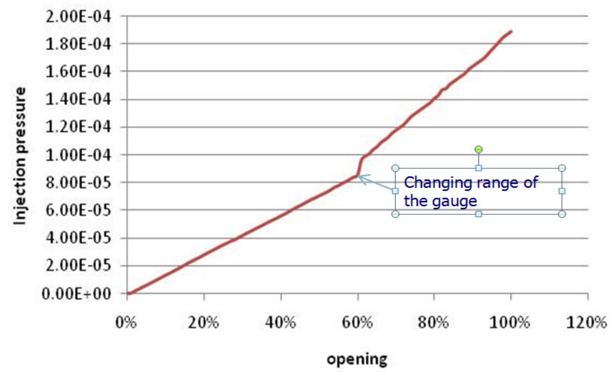

Figure 8: System reproducibility with H_2

The step at 60% for H2 (Fig. 8) is due to the range of the Injection Pressure monitor (10E-5 to 10E-4) so it changes calibration (Pirani gauge).

NEXT STEP: SMART BENCH FOR ECR SOURCE (AUTOMATIC SOURCE)

We already know that UDV valve provided a good stability [4] but the main defaults in this system are:

- The high sensibility to the temperature's variations.
- Hysteresis shape of valve thermo-mechanical response.

The main issue for having a stable beam from an ECR Ion source is the precise control of the gas flow.

Today, we can consider building a smart system for producing Ion beam dedicated to hadron therapy with:

- A high reproducibility of beam parameters.
- An insensibility to low temperature variation.
- And a stable beam with a good Emittance during several weeks without any intervention of operators.

The future system will allow selecting the type of ion (example C^{4+}) and the intensity (200µAe). The system will self-adjust Gas, Focus, Puller, RF-tuner, Frequency and RF power parameters for reaching the desired values after several minutes.

REFERENCES

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